Space Shuttle Orbiter
Main Engine Ignition
Acoustic Pressure Loads Issue

Recent Actions to Install Wireless Instrumentation on STS-129

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Background

- Development Flight Instrumentation (DFI) flights (STS-1 to STS-4) characterized the acoustic pressures produced at Space Shuttle Main Engine (SSME) ignition.

- The engine start sequence varied for each flight to balance the load over numerous flights.

- After the acoustic models were updated, all Orbiter parts evaluated during these DFI flights were deemed good for 100 missions.

- All DFI was removed after STS-4, except one acoustic pressure measurement, which remained in the base heat shield in the center of the 3 engine cluster.

- The acoustic models were updated over time and uncertainties were assessed recently for end-of-life concerns.

- End-of-life issues were briefed at the STS-129 Flight Readiness Review (FRR) Board on Oct 28, 2009 in preparation for a Nov 16, 2009 launch. This board determined that there was NOT rationale to fly with the specific risks identified.

STS-129 Plan

- Primary efforts were to refine the structural and acoustic models to show the Orbiter is good for one flight by the L – 2 day meeting on Nov 14th, 2009.

- Quick turnaround effort occurred to place new instrumentation at appropriate locations to support model validation and refinements for subsequent launches.

- The most critical area needing instrumentation was determined to be the upper attach fitting for the left Orbital Maneuvering System (OMS) pod Reaction Control System (RCS) stinger to the OMS pod with the primary acoustic load facing down and inboard.

- Instrumentation desired is acoustic pressure microphones on and off the vehicle and tri-axial accelerometers in the stinger.

Orbiter Arrives at Wing Leading Edge Impact Detection System (WLEIDS), Government Furnished Equipment (GFE) Solution

- **Kennedy Space Center (KSC) quickly responds and finds that they can add pressure sensors to the Tail Service Mast on either side of the flame trench.**

- **The Orbiter Vehicle Office looks at it's options:**
  - Vehicle Instrumentation – Not flexible enough to handle the schedule.
    - All channels are full – as they should be.
    - Extensive wiring required – long distances to avionics boxes.
    - Avionics are in areas already closed out for flight.
    - At a Shuttle Program meeting on 10/05/09, the conclusion is reached that the OMS RCS microphone sensor monitoring options will not meet the Nov. 16th launch date due to the tile modification work required.
  - Standalone Wireless Add-on Instrumentation
    - Wing Leading Edge Instrumentation (WLEI) is worth evaluating using piezoelectric accelerometers for STS-129 and acoustic pressure sensors on future flights.

GFE Instrumentation Objectives

[redacted]

1) Establish/develop feasible design concepts within schedule, hardware availability and environmental compatibility constraints.

2) Install GFE instrumentation before launch of STS-129.

3) Certify GFE hardware for safety of flight/crew/mission (at a minimum).

4) Prepare to accommodate pressure sensors for STS-130 and subsequent flights.

[redacted]

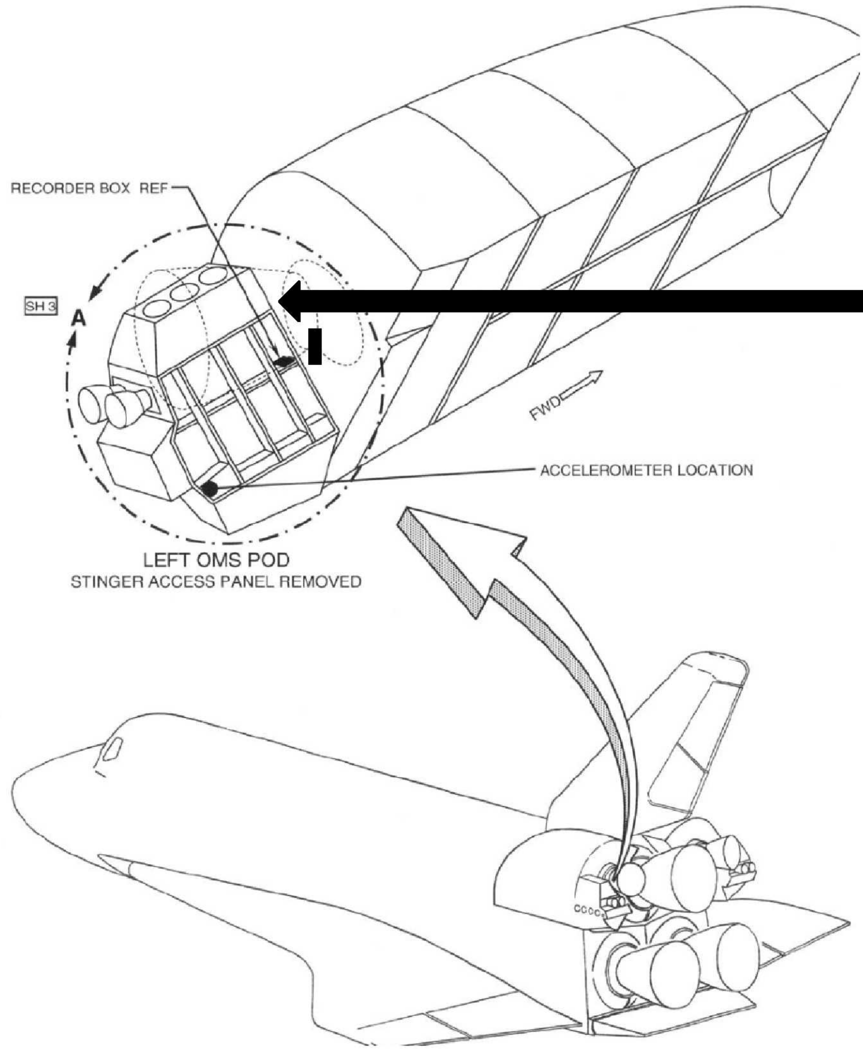
GFE Instrumentation Requirements

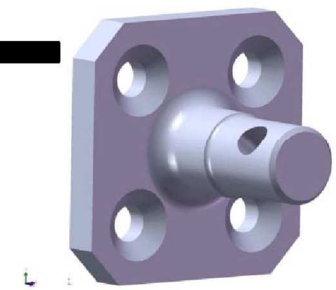
- **General Requirements:**
  - Record T-7 to T-0 acoustic vibration environment.
  - Accommodate launch slips.
  - Data gathering after launch desired, but not required.
  - Data can be downloaded post flight.
  - No power or data interfaces for flight except sensor wires.
  - Maximize reuse of WLEIDS hardware, certification and procedures.

- **Accelerometers:**
  - One Tri-ax – 20K/sec sample rate and high dynamic range.
  - Reduce accelerometer total with increase in acoustic pressure sensors.

- **Acoustic monitoring:**
  - OMS/RCS stinger one or two locations, when schedule permits – STS-130.
  - 20 - 315Hz @ max 180 dB Sound Pressure Level (SPL).

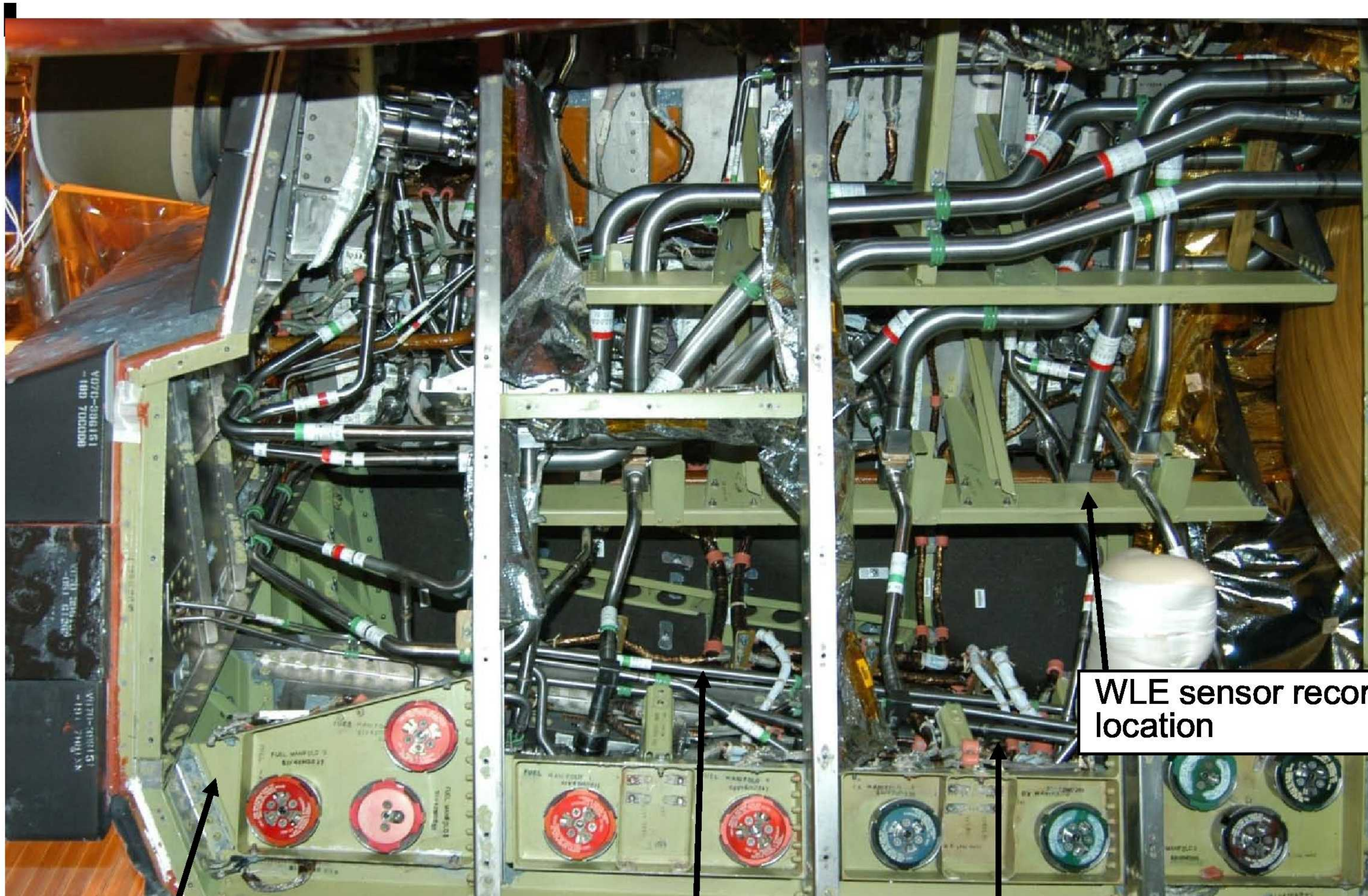
Left OMS/RCS Stinger Monitoring Location for STS-129



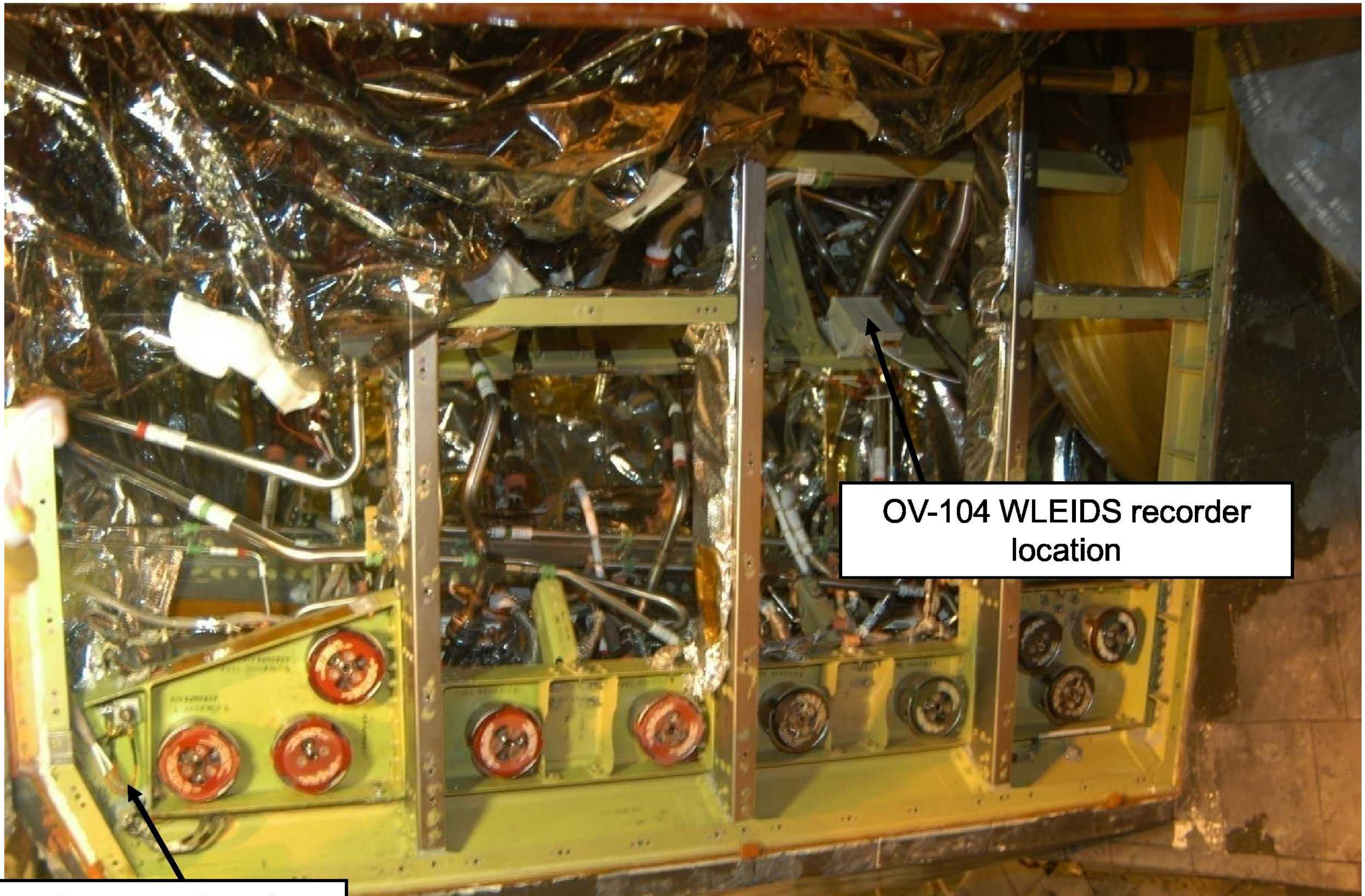


Part with highest concern
RCS stinger attach fitting
(P/N 73A310072)

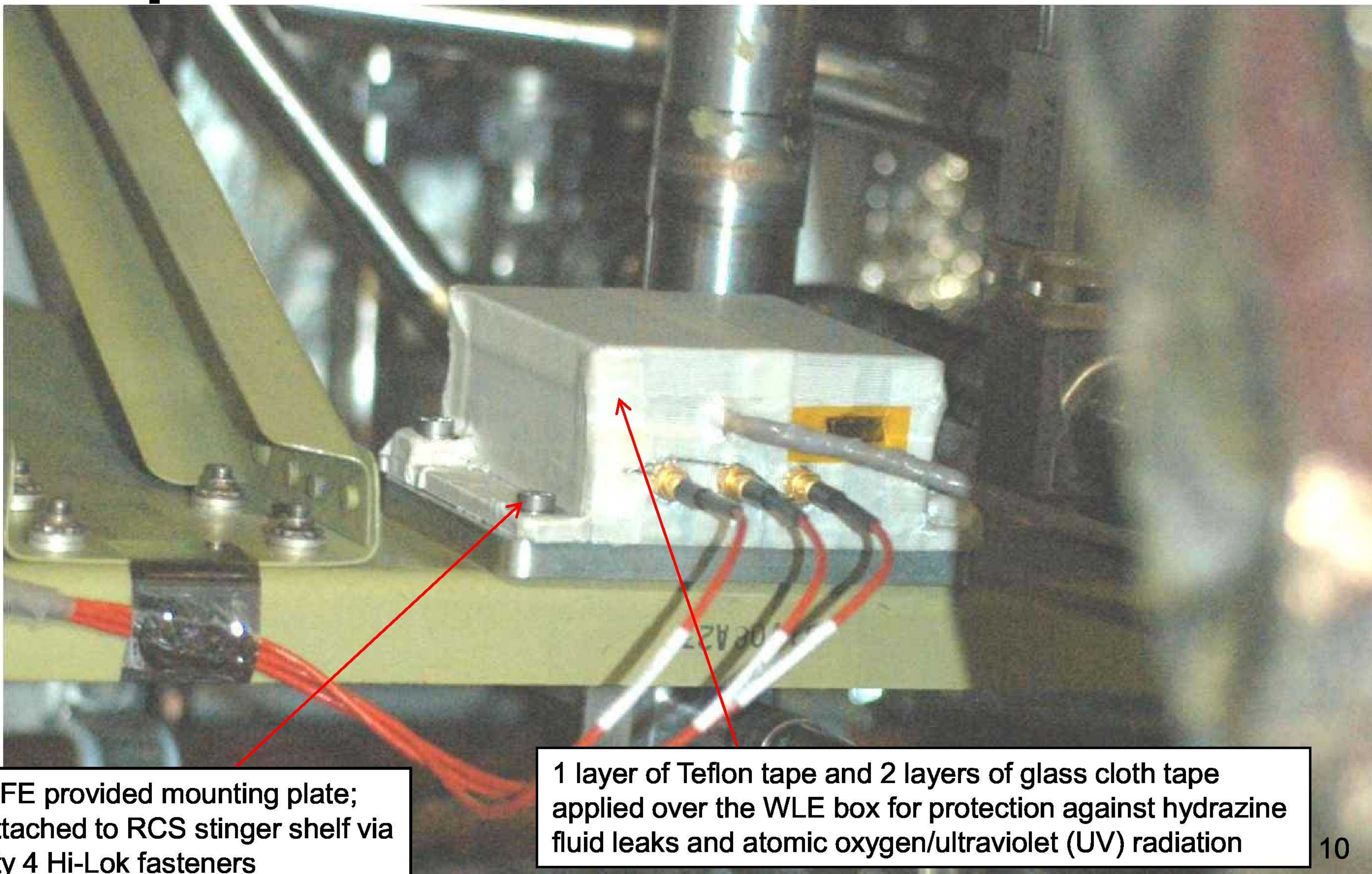
RCS Stinger Door Removed



STS-129/OV-104 Main Engine Ignition (MEI) Instrumentation Closeout Photo



WLE Recorder Box Installation Closeout Picture for STS-129/OV-104



GFE provided mounting plate; attached to RCS stinger shelf via qty 4 Hi-Lok fasteners

1 layer of Teflon tape and 2 layers of glass cloth tape applied over the WLE box for protection against hydrazine fluid leaks and atomic oxygen/ultraviolet (UV) radiation

Wing Leading Edge Impact Detection System

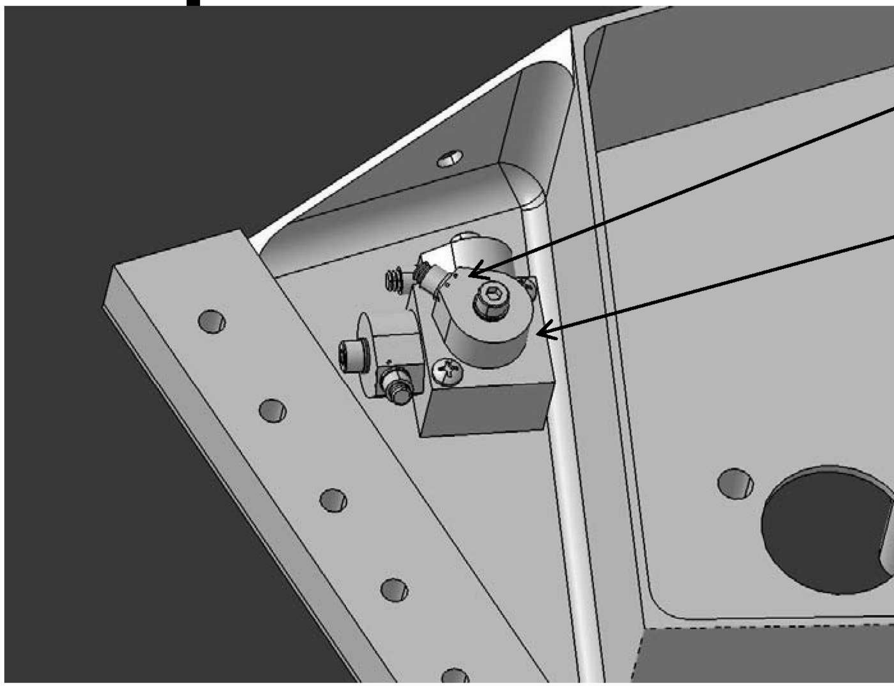
- 915 MHz Radio Frequency (RF) for upload and download

Energizer L91 2-AA pack

- 256 Mbytes data storage
- Universal Serial Bus (USB) download
- Up to 20KHz (3 channels)
- 1 channel Resistive Thermal Device (RTD)
- 3.25” x 2.75” x 1.5”
- Weight ~ 12 oz

- Accelerometer Sensor: Endevco 2221F
  .966”L x .6”W x .52”H
- Accelerometer Mounting Block: Endevco 2950M3

Accelerometer Mounting

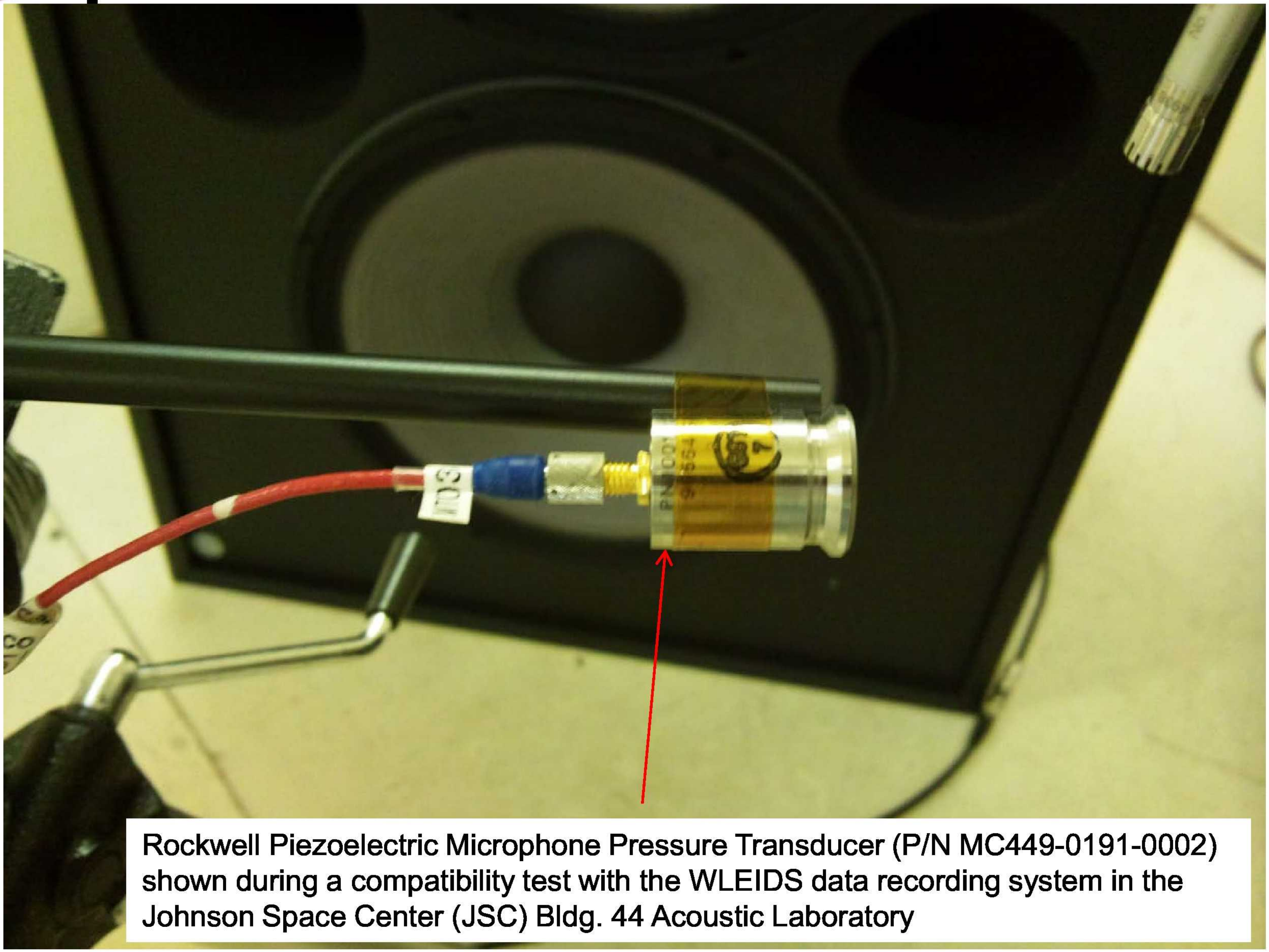


Single Axis Piezoelectric Accel

COTS Mounting Block

Closeout Photo

Acoustic Microphone



Rockwell Piezoelectric Microphone Pressure Transducer (P/N MC449-0191-0002) shown during a compatibility test with the WLEIDS data recording system in the Johnson Space Center (JSC) Bldg. 44 Acoustic Laboratory

Acoustic Microphone Mounting Locations

- Acoustic microphone monitoring in the left OMS RCS stinger location could not be accommodated for STS-129; however, there are currently plans to instrument the next Orbiter Vehicle (OV-105) on STS-130 with microphone sensors, as well as accelerometers.

- Two options currently being assessed are:

1) Install 1 additional acoustic sensor on the OMS/RCS stinger aft access door, unhook the x-axis accel and monitor the y-z planes with the single axis accelerometers in the same location as STS-129.

2) Install 2 additional acoustic sensors; one on the OMS/RCS stinger aft access door, and a second on the OMS/RCS stinger inboard side access door, unhook the x and z accels and monitor the y plane with a single axis accelerometer in the same location as STS-129.

Certification Approach

- Safety Certification: GFE hardware installation for safety of flight.
- Certification for one flight only (STS-129).
- Rely heavily on qualification and demonstrated performance of WLEIDS and the Micro Strain Gauge Unit (MSGU) hardware.
- RF and Electromagnetic Compatibility (EMC) assessment performed by similarity with previous system.
- Joint review of safety hazards presented to Orbiter Project Office and Shuttle Program Management for approval.
- Early concurrence on the process by the GFE team, Engineering, Safety, Orbiter, Space Shuttle and NASA Engineering and Safety Center (NESC), our independent engineering and safety organization created after the Columbia accident.
- Engineering and safety assessments of <u>hardware attachment</u> – "longest pole".

Certification Approach (Cont'd)

Delivered GFE certification products included:

- Material and fracture control certification
- Electromagnetic Interference (EMI) (Radiation emissions/RE102 & RE103) assessment
- RF usage/location assessment
- L91 battery assembly certification for OMS Pod/RCS stinger location
- Structural assessment for hardware environment and mounting locations
- Safety Issue Briefing
    - Necessary control verification documentation for hazards
- Hardware & installation drawings/specification datasheets
- Government Certification Approval Request (GCAR)

MEI GFE Instrumentation "As-Run" Schedule for STS-129

10/28	STS-129 FRR issues actions
10/30	Sensors and acquisition parameters determined, Vehicle instrumentation options ruled out
10/30	KSC/Structures captures photos of potential locations for sensors and Data Acquisitions (DAQs)
11/1	Inventories checked and initial test plans determined
11/2	KSC shipped acoustic pressure sensor overnight to JSC for testing
11/3	JSC/EV tests acoustic pressure sensor range compatibility with WLEIDS DAQ
11/3	Orbiter/EV present instrumentation options and status to Orbiter
11/3	Safety cert approach acceptable based on delta from previous cert in same zone
11/4	JSC Engineering approves integrated Orbiter and EA GFE plan
11/4	KSC Engineering and Ground Ops reviews options and schedules
11/4	Boeing HB provides engineering assessment and hardware configuration input
11/4	JSC/EV management (GFE Flt HW Rvw) agrees to ship flight hardware with minor open certifications
11/4	JSC/EV purchases accelerometer mounting blocks from Endevco – overnight shipping
11/5	Space Shuttle Program Manager approves triax accel only for STS-129, no launch slip
11/5	JSC/EV and Safety reviews updated flight hardware certification and safety cert packages
11/6	JSC/EV ships most flight hardware to start install of cables and accels NLT 11/9
11/7-9	JSC/EV fabricate flight mounting plates
11/8	KSC receives non-flight mounting block for fit checks and final locating
11/9	JSC/EV GFE operations expert hand-carries accel blocks and mounting plate to KSC for installation
11/9	KSC installation begins, estimated completion is 11/11 .
11/10	Obiter Project reviews Safety Issue Brief/Hazard Analysis Summary - Multiple safety orgs participate
11/10	Orbiter signs GCAR certification & Change Request (CR)
11/12	Space Shuttle Program Change Board approves Safety Issue Briefing
11/13	KSC Instrumentation group wirelessly uploads WLEIDS flight instructions (like other WLEIDS sensors)
11/14	L-2 Review – final questions answered concerning safety of installation
11/16	Launch of STS-129

Summary

- In a quick response to end-of-life issues with vehicle components related to environment and structural uncertainties, the Space Shuttle Orbiter team was able to avert delays and increase safety by utilizing a flight-ready standalone data logger with wireless capability.

Recommendations

- Build a "tool kit" of add-on sensors and data acquisition systems that have short turnaround to being applied for various ground test and flight environments.
- Develop quick turnaround processes that enable the items in the tool kit to be used or flown in non-critical applications.
- Ensure there is a team who knows the process of getting items quickly integrated into the vehicle and mission.
- As Shuttle retires, there is an inventory of WLEIDS and other add-on instrumentation that should be made available for other vehicles and testing, as required.

Backup Slides

WLEIDS/MEI Team

Orbiter Project Office

M. Garkse – Project Manager
C. Martin – SE& I Manager
B. Lane – OV-104 Orbiter Vehicle Manager
R. Allison – OV-105 Obiter Vehicle Manager
K. Brown – FCE and GFE Manager
P. Rivero – SSP Safety & Risk Manager

JSC GFE Engineering

B. Villarreal – EV17 Office Manager
S. Morgan – Deputy EV17 Manager
R. Nuss – EV DCE for Orbiter
N. Wells – NASA Project Manager
G. Studor – WIS Hardware Specialist
S. Hafermalz – WIS Hardware Specialist
J. Nguyen - WIS Hardware Specialist
H. Lewis – ESCG Project Manager
S. Boehm – Project Engineer
H. Ong – Project Engineer
M. Garcia – Project Engineer
J. Feng – Project Engineer
C. Stephens – Project Engineer
L. Simle – Project Engineer
S. Reno – Project Support
V. Abrignani – Safety Engineer
A. Le / M. Shoeb – Structural Engineers
M. Maculo /G. Galbreath– Structures/ES
C. Chang/ N. Martinez – M & P Engineers
H. To – Quality Engineer
B. Scully / M. Krome– SSP E3 Chairs
C. Sham – RF Engineer
J. Jeevarajan – Battery Engineer
C. Garland – Certification and Compliance
G. Sherrill – Certification and Compliance
A. Belote – Mechanical Designer

KSC Ground Ops

A. Sherman - NASA/INS
J. Huet – USA/INS
E. Taylor – OV105/4 Instr lead
C. Reiber – USA/Avionics
R. Larson – Boeing Instr
R. Day – Boeing Instr.
A. Micklos – USA Proj Mgr
J. Johnson – USA Proj Mgr
K. Jackson – KSC Logistics

Orbiter Structural Engineering

K. Bernstein – NASA/Orbiter Loads Panel Chair
M. Dunham – Structures Lead/Boeing
A.Gilmore – Orbiter Structures DCE
J. Broughton – Orbiter Structural Eng at KSC

Orbiter Sustaining Engineering Boeing/Huntington Beach

K. Hinkle – Project Manager
S. Billeter
D. Brewster - Drawings,Tech Order s
Frank Biele – Designer
M. Koharchik – Structural Analyst
Bob Hill – Loads Environment
Bill McKee - Instrumentation

Safety & Mission Assurance

R. Comin – FESRRP Chair
S. Nakamura – JSERP Chair
B. Abshier – GFE S&MA Lead
E. Volter – GFE S&MA Engineer
B. Vheena – GFE S&MA Engineer
J. Nugent - GFE S&MA Software

Orbiter Instrumentation Boeing/Houston

D. Favors - Orbiter Instrumentation

WLE Sensor Specifications

Specification	Condition/ Parameter	Min	Typical	Max	Units
Input Range:					
Sensitivity	Accel = 10 pC/g		1.67		mV/g
Full Scale[1]	Positive		750		g
Operational[1]	Negative		-750		g
Measurement Performance:					
Resolution[1,2]			40	75	mg
Dynamic Range[3]		80	86		dB
Accuracy	Electronics alone @ 70 F		0.4g +1% of reading	0.75g +2% of reading	
Frequency Characteristics:					
Sample Rate		19.99 8	20.000	20.002	KHz
Channel Phase Matching	10Hz to 200Hz		2.5	5	degrees
Sample Clock Sync.				30	μs
Anti-aliasing Lpass Filter	-3dB point	5.8	6	6.2	KHz
	Slope		-18		dB/octave
	Alignment		3rd order Butterworth		
High-pass Filter	-3dB point	9.5	10	10.5	Hz
	Slope		+6		dB/octave
	Alignment		1st order Butterworth		

- **Notes:**
- **[1]Equivalent acceleration value listed is derived from the electrical characteristics of the data acquisition electronics and translated to acceleration based on sensitivity listed.**
- **[2] Resolution is defined as the RMS summation of the background noise components between 10Hz – 5000Hz.**
- **[3] Dynamic range is defined as the maximum sine wave input divided by the measured resolution**